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Application of polar-orbiting, meteorological satellite data to detect flooding of Rift Valley Fever virus vector mosquito habitats in Kenya

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Abstract. Measurements of green-leaf vegetation dynamics recorded by the advanced very high resolution radiometer instruments onboard National Oceanic and Atmospheric Administration satellites 7 and 9 were used to derive ground moisture and rainfall patterns in Kenya and monitor resultant flooding of mosquito larval habitats (dambos) likely to support Rift Valley Fever virus vector mosquitoes (*Aedes* and *Culex* spp.). Satellite-derived data from mid-1981 to December 1988 have been analysed with corresponding rainfall, flooding and vector population data as they relate to Rift Valley Fever virus ecology. Single (7×7 km) and multiple grid-cell image analysis (200×300 km) in small localized areas and large geographical regions, respectively, of vegetation data were used to quantify the potential for flooding of mosquito breeding habitats. The ability to detect accurately parameters, such as ground moisture, that determine flooding could provide local officials with sufficient warning to allow for implementation of specific mosquito control measures before a disease outbreak.

Key words. Satellite remote sensing, Rift Valley Fever virus, flooding, mosquito larval habitats, dambos, *Aedes*, *Culex*, Kenya.

Introduction

Epizootics of Rift Valley Fever (RVF) virus in Kenya are associated with seasonal rainfall produced by a strong intertropical convergence zone (ITCZ) (Davies *et al.*, 1985). Rainfall is thought to precipitate RVF virus outbreaks by

flooding mosquito breeding habitats (dambos) and producing a hatch of primary (*Aedes* spp.) and upsurge of secondary (*Culex* spp.) vectors (Linthicum *et al.*, 1985). The ability to detect parameters of rainfall and ground moisture that determine flooding could provide local officials with sufficient warning to allow for implementation of specific vector control measures before a disease outbreak.

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Rainfall patterns and ground moisture changes can be derived from measurements of green-leaf vegetation dynamics recorded

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by advanced very high resolution radiometer (AVHRR) instruments on polar-orbiting, meteorological satellites (Tucker *et al.*, 1985). Davies (1975) reported that the epizootic range of RVF virus in Kenya is almost entirely restricted to ecological zones II, III and IV as defined by Pratt *et al.* (1966). These ecological zones are found principally along a narrow coastal strip and in the central and western highland areas extending to Lake Victoria and the Uganda border. Linthicum *et al.* (1987) demonstrated how AVHRR data could be used to infer ecological parameters associated with RVF viral activity in ecological zones II and III. This study describes the use of AVHRR imagery onboard National Oceanic and Atmospheric Administration (NOAA) satellites to relate rainfall patterns, vegetation changes and flooding of mosquito vector habitats within a RVF virus epizootic region in ecological zone III.

Materials and Methods

Observations on rainfall (Fig. 1), flooding of mosquito habitats and green-leaf vegetation changes were made in a study area located approximately 8 km SE of Ruiru, Thika District, Central Province, Kenya ($1^{\circ}12'S$, $37^{\circ}E$; 1500 m) (Fig. 2). The study area was located in a dry, subhumid to semi-arid region of bushy grassland without forest. *Combretum* and *Acacia* spp. and other evergreen trees and shrubs were predominant. Monthly rainfall data were recorded at Jomo Kenyatta International Airport, Nairobi ($1^{\circ}20'S$, $36^{\circ}56'E$) and obtained from the Kenya Meteorological Department. There are two rainy seasons during the year, coinciding with the position of the ITCZ. The short rainy season, which generally extends from October to December, and averages less rainfall than the long rainy season which extends from March

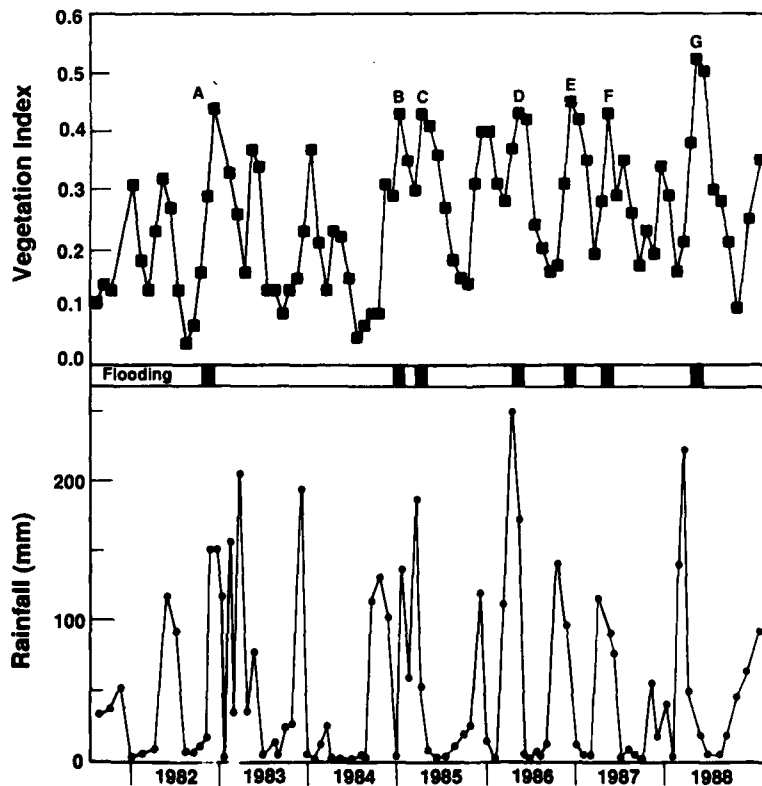


Fig. 1. Plots of AVHRR NDVI values and monthly rainfall data from October 1981 to December 1988. Each NDVI value plotted is a monthly composite for a single grid cell (centred at $1^{\circ}20'S$, $37^{\circ}E$) or approximately 49 km^2 .

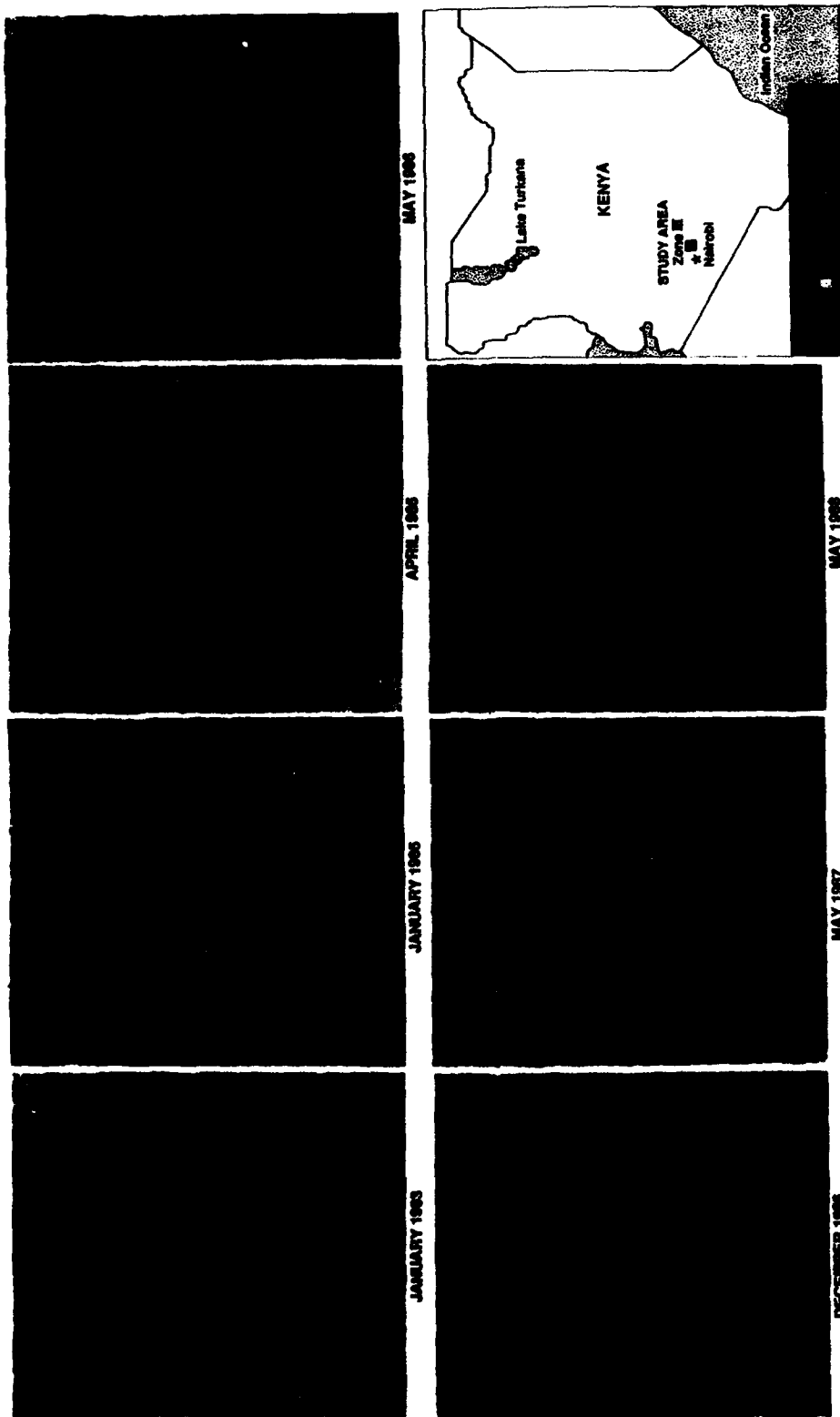


Fig. 2. AVHRR NDVI composite, Mercator projection images of Kenya for months corresponding to mosquito vector habitat flooding and maximum vegetation development at 1°20'S, 37°E during the period from October 1981 to December 1988.

to June. Observations of the flooding of potential mosquito vector habitats were made from October 1981 to December 1988.

Digital remote-sensing data were produced by the AVHRR sensor on NOAA-7 and -9 satellites for a single 7×7 km grid cell (pixel) site centred over the study area. Weekly AVHRR data were derived from the global-area-coverage data produced by the on-board processing of large-area-coverage data (1.1×1.1 km) and transmitted to receiving stations in Virginia or Alaska, U.S.A. (Tarpley *et al.*, 1984). The normalized-difference vegetation index (NDVI) analysed in this study is a transformation between data from the visible channel (Ch 1, 0.58–0.68 µm) and the near-infrared channel (Ch 2, 0.725–1.1 µm) and is expressed by $NDVI = (Ch\ 2 - Ch\ 1) / (Ch\ 2 + Ch\ 1)$. To obtain data which were largely cloud-free and with low-aerosol conditions, weekly composite data were formed by selecting the highest NDVI for each grid-cell location from the daily data for that week (Holben & Fraser, 1984). Weekly NDVI data for each grid cell in Kenya were calculated and mapped to a Mercator projection. The highest value during each one month was selected to represent the 1-month composite for each grid cell location. Compositing was performed on the Hewlett-Packard 1000 and Ramtek image-processing system.

Results

The average yearly rainfall for 1982–88 was 657 mm. Rainfall during the short and long rainy seasons averaged 328 mm and 248 mm, respectively (Fig. 1). In general, rainfall patterns of 1982–84 were irregular and inconsistent, while in 1985–88 rainfall was more consistent during both the short and long rainy seasons.

The relationship between NDVI data, rainfall and the flooding of RVF mosquito-vector breeding habitats from 1 October 1981 to 31 December 1988 is illustrated in Fig. 1. During the 87-month study, rainfall induced the flooding of two or more dambo habitats for a period of at least 2 days in the study area on seven occasions. The flooding of mosquito-breeding habitats resulted in the production of at least some adult *Aedes* mosquitoes on five occasions: December 1982, May 1986, December 1986,

May 1987, May 1988 (points A, D, E, F, G, Fig. 1). Only limited flooding (<4 days duration) occurred in January (point B, Fig. 1) and April (point C, Fig. 1) 1985, and no adult *Aedes* mosquitoes emerged. Flooding occurred just before or coincided with peak NDVI values and followed periods of 1–3 months of rain totalling more than 200 mm. Normalized difference vegetation index values at or above 0.43 corresponded to at least short-term flooding of vector mosquitoes' breeding habitats. No flooding occurred when NDVI values were below 0.43. High NDVI values generally corresponded with high rainfall.

Monthly NDVI data were calculated and re-plotted on Mercator projections by assigning brown, gold, green, red, pink, blue and purple to increasing NDVI values from 0.0 to 0.6, as indicated by the colour bar chart (Figs 2 and 3). Monthly NDVI images of Kenya, representing periods of flooding during the study, are illustrated in Fig. 2. Colour NDVI images for months of maximum NDVI values (>0.43 in the study area) can be used to demonstrate visually that January 1983 (point A, Fig. 1) and May 1988 (point G, Fig. 1) represented the months of most intense NDVI values in Kenya. The NDVI data for these two months correlated with periods of high rainfall and extended habitat flooding. For comparison, NDVI images of Kenya, representing periods of minimum vegetation index values for each year of the study, are illustrated in Fig. 3. The NDVI values for September 1982 and 1983, and July 1984 are lower than the values for October 1985, September 1986 and 1987, and October 1988, reflecting the irregular rainfall patterns of 1982, 1983 and 1984 (Fig. 1). These differences are readily visible in the Fig. 3 image.

Discussion

The annual mean rainfall for 1982–88 was less than the long-term (1959–80) rainfall mean of 762 mm. Rainfall during the 1982–88 short rainy season equalled the corresponding mean of the long-term short rainy season.

Although total rainfall amount is not the only factor that influences NDVI values, a correlation between NDVI data, which represent the photosynthetic capacity of the area measured (Sellers, 1985), and rainfall has been demon-

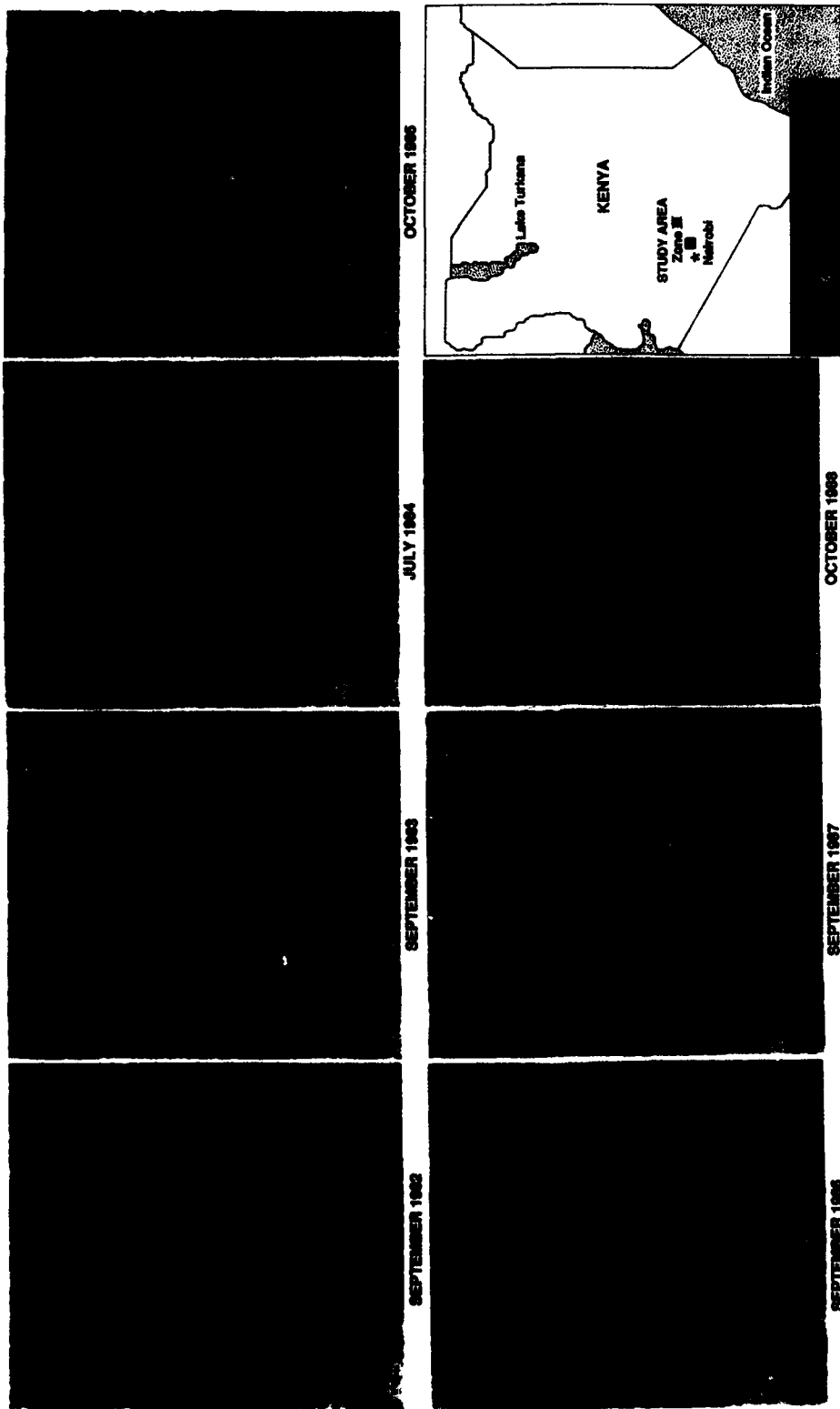


Fig. 3. AVHRR NDVI composite, Mercator projection images of Kenya for the months of minimum vegetation index values for 1982-88.

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strated. The observations made in this study corroborate earlier reports that, in general, the NDVI is a reliable indicator of rainfall (Tucker *et al.*, 1985; Linthicum *et al.*, 1987). The further correlation between high NDVI values and flooding of mosquito breeding habitats is a new and important extension of previous observations. The ability to detect remotely flooding of mosquito habitats at one site in ecological zone III suggests the possibility of extrapolating these results to other similar habitats within zone III. Additional observations should be made in other areas to determine if flooding corresponds with NDVI values that exceed a value of 0.43. Further studies must also be conducted to attempt to quantify the length of time that flooding occurs in relation to NDVI values, as the number of primary and secondary mosquito vectors that emerge is dependent upon the length of time the habitat remains flooded.

The ability to detect and monitor flooding of vector habitats effectively has important implications for developing strategies for mosquito control and disease prevention. Effective mosquito control efforts might prevent transmission of the RVF virus to susceptible vertebrate hosts by transovarially infected *Aedes* spp. or by blocking secondary transmission by *Culex* spp. and other epizootic vectors. The ground observations and remote sensing technology discussed here for RVF virus should have relevance to other vector-borne diseases that are dependent upon the seasonal inundation of vector habitats and could have an impact on the development of their control strategies.

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